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Mishin Monograph on Failure of Soviet Manned Lunar Program

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[Monograph by V. P. Mishin: "Why Didn't We Fly to the Moon?"]

[V. P. Mishin; NOVOYE V ZHIZNI, NAUKE, TEKHNIKE: SERIYA KOSMONAVTIKA, ASTRONOMIYA, No 12, 1990]

[Text]

Introduction

"Why didn't we fly to the moon?" is a question that is being asked more and more often. That subject was strictly classified, and it is only recently that certain information about our lunar program has appeared in the open press. One can agree with the author of the booklet "The Apollos Fly to the Moon,"[1] who wrote that the successes of even the United States in landing American astronauts on the Moon's surface were reported by our mass media in a clearly biased and inadequate manner. Concealing the facts, we made it look as if no work was being done in the USSR on a manned flight to the Moon and as if our efforts were being concentrated solely on lunar research via unmanned space vehicles. Moreover, we even began to assert that lunar exploration could be managed with just unmanned vehicles and that there was nothing for a person to do on the Moon.

The time has now come not only to state outright that there was a manned lunar flight program in our country, but also to talk about its details. Unfortunately, it did not have a far-reaching goal and was driven by considerations of prestige only—to perform a circumlunar mission and then to land a person on the Moon's surface, before the Americans did.

The first to get involved in work on getting to the Moon was the collective headed by S. P. Korolev. The chief designer charted the actual paths for a circumlunar mission performed by cosmonauts, plus their landing on the Moon's surface and their return to Earth. The Luna unmanned space vehicles were stages in the testing of equipment components and ground facilities of rocket-space systems for the study of the Moon with manned spacecraft. Deep space, the Moon, the closest planets of the solar system—those were the goals of his entire life.

So why, then, were those projects not completed after his sudden, premature death? Why didn't we fly to the Moon?

Those are the questions that I have tried to answer in this booklet.

Unmanned Vehicles Conduct Reconnaissance

Landing a person on the Moon is a necessary step for increasing mankind's knowledge of the universe. Both in our country and in the United States, the preparations for manned missions to the Moon were preceded by a study of the Moon with unmanned space vehicles. The engineering principles of the systems (both on-board and ground systems) that were needed to support the movement of the space vehicles along desingated trajectories and their landings on the Moon's surface in designated regions had to be tested, and the conditions that would support a human on its surface had to be determined. Developed for those purposes in the United States were the Pioneer and Ranger unmanned space vehicles. They were designed to study flight trajectories to the Moon and to examine its surface from fly-by trajectories. Also developed were Lunar Orbiter vehicles, which were used for photographing the Moon's surface from circumlunar orbit, and Surveyor vehicles, which were used to test the lunar landing systems and which studied its surface. The reader may acquaint himself in more detail with the results of the launches of those unmanned space vehicles in the previously mentioned booklet by G. M. Salakhutdinov.

The launches of the unmanned lunar space vehicles developed in the OKB [Special Design Bureau] headed by S. P. Korolev can be divided into two stages.

The first stage consisted of the Luna-1, -2 and -3 unmanned interplanetary probes (Figure 1). They were launched by the Vostok three-stage launch vehicle with the Ye rocket unit, which had the RO-7 oxygen-kerosene liquid-fuel rocket engine, which was designed by the OKB headed by S. A. Kosberg (Figure 2). That unit ignited after the central unit's steering engines cut off. The purpose of the launches of this generation of probes (their masses did not exceed 300 kg) was to perfect the trajectories of unmanned space vehicles launched from Earth by means of a continuous acceleration during the powered-flight phase of the trajectories. Luna-3 was equipped with an attitude control system, which made it possible to photograph the Moon's dark side and to transmit the images back to Earth. The launch of that vehicle laid the foundation for the development of space-vehicle control-of-motion systems.

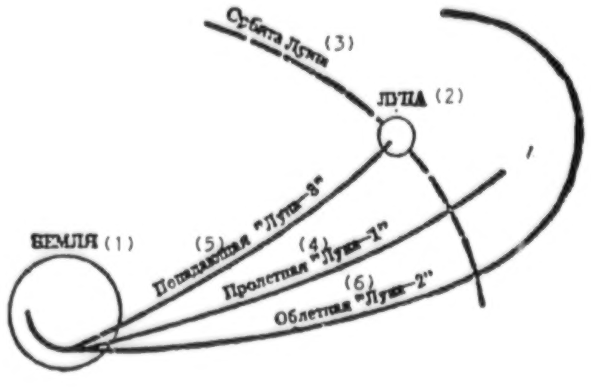


Figure 1. Trajectories of Luna-1, -2 and -3 unmanned interplanetary probes launched with the Vostok launch vehicle with the Ye rocket unit

Key: 1. Earth—2. Moon—3. Moon's orbit—4. Luna-1 fly-by trajectory—5. Luna-2 impact trajectory [mislabeled as Luna-3]—6. Luna-3 circumlunar trajectory [mislabeled as Luna-2]

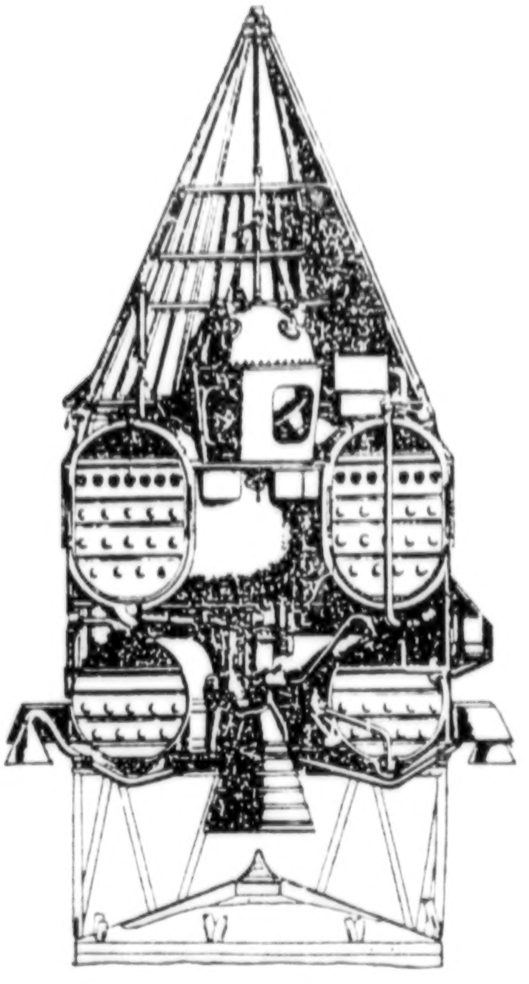


Figure 2. The Ye rocket unit

The second stage consisted of the Luna-4 through -9 unmanned interplanetary probes, which were launched with the Molniya four-stage launch vehicle (Figure 4) with the "I" and "L" rocket units. The third stage's "I" rocket unit had the RO-9 oxygen-kerosene LPRE [liquid-propellant rocket engine] (also designed by S. A. Kosberg's "firm") which ignited right after the cut-off of the central unit's steering engines in the initial powered phase. The fourth stage's "L" rocket unit had the S1-5400 oxygen-kerosene LPRE developed in our OKB. It had a power-to-mass ratio that was good for that time, and it had been adapted to ignite after a lengthy stay in weightless conditions. The L rocket unit also had a system for firing the main engine and an attitude control system. They were mounted on a truss that separated from the L unit after the main engine fired.

After the fourth stage, with the L rocket unit, was inserted into an artificial Earth satellite orbit, it flew for some time with a switched-off engine. At a specified moment, the attitude of the stage was changed, and the engine ignited, boosting the probe to a velocity close to escape velocity.

That type of acceleration method made it possible to carry out flights to the Moon with identical power consumption on any day regardless of the Moon's position in orbit and to increase the mass of the second-generation Luna vehicles from 300 to 1600 kg. That made it possible for S. P. Korolev to move on to work on the soft landing on our planet's satellite. In the period from 2 April 1963 through 4 November 1965, five such unmanned vehicles were launched—Luna-4, -5, -6, -7 and -8—and only the launch of the 1,893-kg Luna-9 (Figure 5), which was carried out on 31 January 1966 (after S. P. Korolev's death), ended in success. The descent vehicle, with a mass of around 100 kg, touched down in the region of the Ocean of Storms at a point with the coordinates 7° N lat and 60° W long. For the first

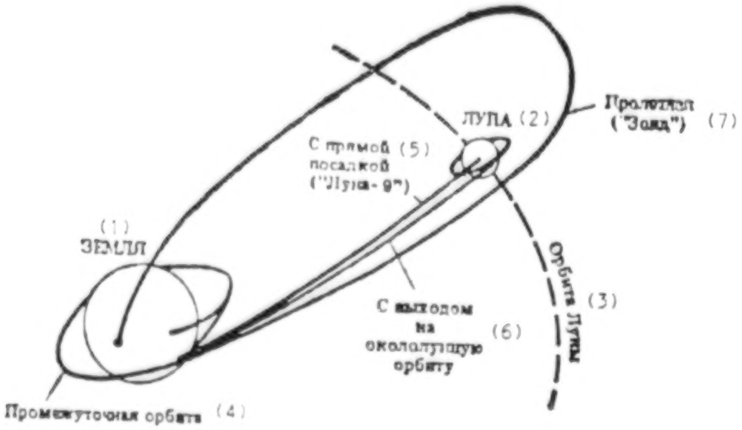


Figure 3. Trajectories of second-generation unmanned interplanetary probes launched with the Molniya launch vehicle

Key: 1. Earth—2. Moon—3. Moon's orbit—4. Parking orbit—5. Trajectory with direct landing (Luna-9 craft)—6. Trajectory with insertion into circumlunar orbit—7. Fly-by trajectory (Zond craft)

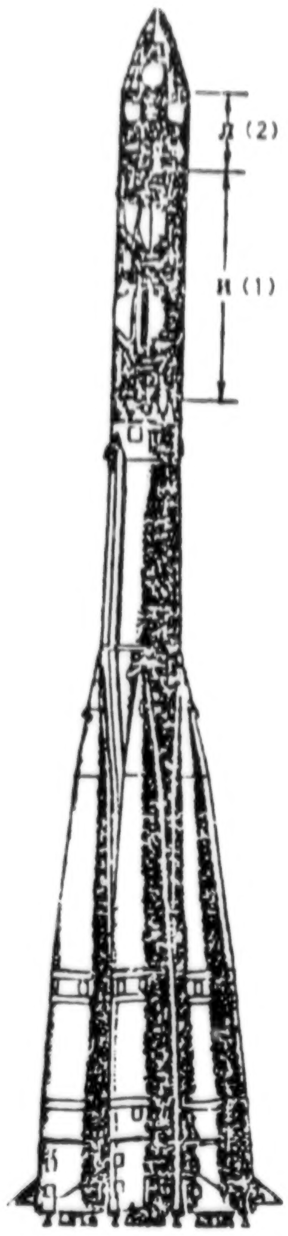


Figure 4. The Molniya launch vehicle

Key. 1. I rocket unit—2. L rocket unit

time in history, a soft landing had been made on the Moon's surface, and a panorama of the lunar surface had been transmitted to Earth.

In 1964 and 1965, the same Molniya launch vehicle was used to launch three unmanned vehicles—Zond-1, -2 and -3—to perfect their control of motion on remote interplanetary paths. On its flyby near the Moon, the last of them took photographs and transmitted back to Earth images of the surface of the dark side of the Moon (including part of the surface not covered by Luna-3's photography).

In 1965, the work involving Korolev's study of the Moon with the second-generation probes was transferred (together with a large stockpile of completed research) to the OKB headed by G. N. Babakin. There, the work was taken further, and it led, as is well known, to the development of the lunar craft that brought back samples of lunar soil to Earth, as well as the famous Lunokhod-1 and Lunokhod-2 [lunar rover vehicles]. All the while, use was made of the launch vehicles developed in S. P. Korolev's OKB. Sergey Pavlovich himself and his group engaged primarily in the development of the rocket-space systems for manned spacecraft.

Apollo/Saturn Program

Landing cosmonauts on the Moon's surface and returning them to Earth required a substantial increase in the mass of a payload that could be inserted into near-Earth orbits, and power-to-mass expenditures increased accordingly.

Those expenditures were a function of the design and composition of the rocket-space system that was to solve the problem, and they, in turn, were a function of the location of the recovery capsule that would be used for the safe return of the mission's participants to Earth. The capsule could be placed into a near-Earth orbit and could remain there until the return of the mission crew, whose members would then transfer to it for the return to Earth. The recovery capsule could be placed into a circumlunar orbit and wait there for the crew that had made a landing on the Moon in order to return the crew directly to Earth. Also possible was a profile in which the recovery capsule and a crew could be sent directly to the Moon's surface and returned to Earth.

It is obvious that the design of the recovery capsule in the second and third instances had to take into account reentry into the Earth's atmosphere (during the return to Earth) at escape velocity. The missions could be performed with either a single launch of a heavy launch vehicle, which would insert the lunar rocket system into a near-Earth orbit, or with several (lighter) launch vehicles, which would insert sections of the lunar orbital complex into either near-Earth or circumlunar orbits, where they would then dock. NASA examined two profiles for a mission to the Moon's surface—one with a rendezvous in a near-Earth orbit, and one with a rendezvous in circumlunar orbit.

Initially, the plan with rendezvous and docking in a near-Earth orbit was selected. Two versions of a two-launch plan were considered: a rendezvous with docking and a rendezvous with refueling. However, in June 1962, with the direct support of President Kennedy, NASA settled on its choice of a single-launch profile with a rendezvous in circumlunar orbit of the lunar module's ascent stage with the Apollo spacecraft's orbiting (main) module, which included the reentry vehicle. In that profile, the Saturn 5 launch vehicle's third-stage S-IVB booster with the J-2 oxygen-hydrogen engine would first

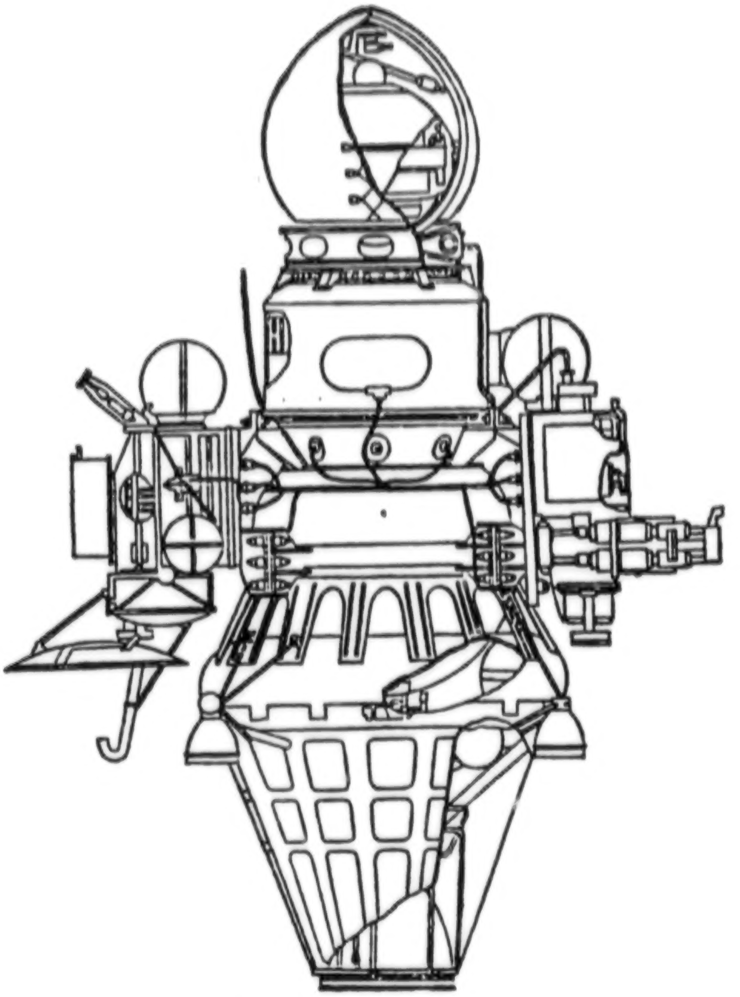


Figure 5. Luna-9 spacecraft

insert the Apollo spacecraft into a near-Earth orbit and then into a trajectory to the Moon.

Figure 6 shows the lunar mission profile for the Apollo/Saturn 5 program. The drawback of that profile was the impossibility of saving the crew of the lunar module's ascent stage if it did not manage to rendezvous with the Apollo craft's orbiting (main) module, which had remained in circumlunar orbit. In addition, with that profile, there was a time limitation on the lift-off of that stage from the Moon's surface that depended on the orbiting module's orbital parameters. To put it simply, the cosmonauts were supposed to wait around until the orbiting module had circled the Moon and was above them, and only then were they to lift off from the surface. Finally, the profile had a constraint on the regions the lunar module could use when it landed on the Moon's surface, which also depended on the orbiting module's orbital parameters.

The work on that program in the United States began in 1961 after Yu. A. Gagarin's flight of 25 May 1961. J. Kennedy, who replaced D. Eisenhower in the post of president of the United States in 1960, addressed Congress (contrary to tradition) in a "Second State of the Union" message. "I believe," he said, "that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to earth." That speech also served as the starting point for the work on the Apollo Program.

The launches of the first Soviet satellites and the first man into space shattered the myth about the limitless scientific and technical superiority of the United States over the USSR and called into being that particular space program of theirs, which opened up a new space race between the United States and the USSR.

The landing of American astronauts on the Moon before 1970 was declared a national goal of the United States, and the mobilization of the nation's resources to achieve that goal was comparable to the mobilization of resources for a top-priority wartime program. Very large

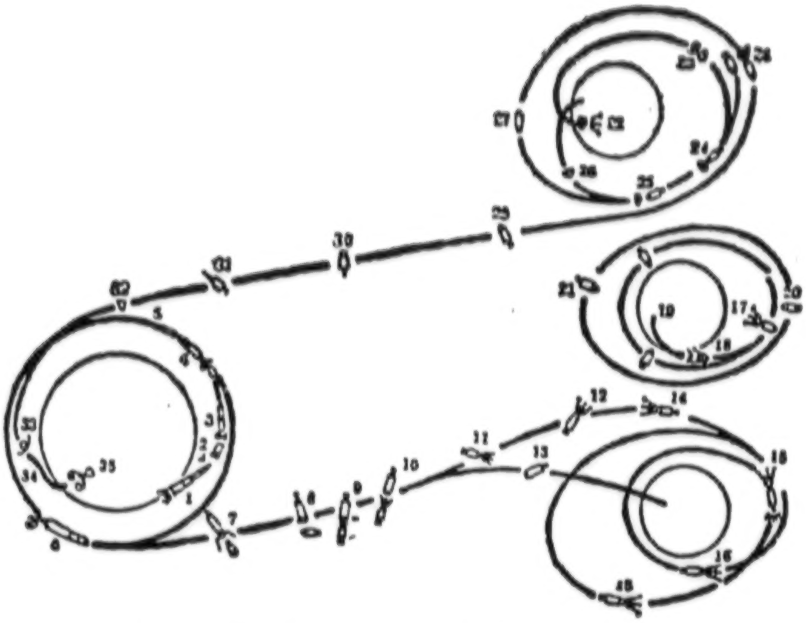


Figure 6. Mission profile of manned lunar mission for Apollo/Saturn 5 program

Key: 1. Lift-off from Earth—2. Separation of first stage booster and firing of second stage's propulsion system—3. Separation of second stage booster and firing of engine of third stage, which inserts Apollo vehicle into low orbit—4, 5. Parking orbit—6. Second firing of third stage's engine at a calculated point in the orbit and insertion of Apollo vehicle into translunar trajectory—7. Separation of main module [command/service modules, or CSM]—8. Jettisoning of conical adapter and transposition of CSM—9. Docking of CSM to lunar module—10. Separation of Apollo vehicle from third-stage booster—11. First mid-course correction—12. Second mid-course correction—13. Third-stage booster transferred to trajectory for direct impact on Moon's surface—14. Last course correction—15. Lunar orbit insertion—16. Establishment of lower [descent] orbit and transfer of two astronauts into lunar module via internal tunnel—17. Separation of lunar module and CSM—18. Firing of lunar module engine for deceleration during landing on Moon—19. Landing maneuver and, after landing of lunar module, emergence of astronauts onto Moon's surface—20. CSM's movement along the orbit—21. Establishment of CSM's orbit just prior to docking—22. Lift-off of lunar module ascent stage from Moon's surface—23. Ascent stage's rendezvous with CSM—24. Docking of ascent stage with CSM, which assumes role of active ship during docking—25. Separation of ascent stage after transfer of the two astronauts from it to CSM unit—26. Jettisoning of ascent stage to Moon's surface—27. Separation of unmanned satellite in orbit—28. Trans-Earth injection—29. First mid-course correction—30. Second mid-course correction (if needed)—31. Separation of command module (recovery capsule) and service module with CSM's propulsion system—32. Orientation of recovery capsule just prior to reentry—33. Recovery capsule in controlled descent phase in Earth's atmosphere—34. Radio blackout during reentry—35. Triggering of parachute system and splashdown of recovery capsule with the three astronauts in specified region of ocean

sums of money were appropriated for solving that problem—the equivalent of $472 for each American family. During the peak period (1966), around half a million people from 20,000 companies were participating in the work on the program.

From the very start of the work on the Apollo/Saturn program, the problems were clearly stated, and organizational structures were found which made it possible to reduce to a minimum bureaucratic red tape and to lower as much as possible (without detriment to the work at hand) the level at which crucial decisions were made.

The program was not cloaked in secrecy, which facilitated the free exchange of data between all the interested organizations, and the flow of information was organized not only vertically (from the higher organizations to the lower, and vice versa), but also horizontally, i.e., between contractors. The free flow of information made it possible to track and monitor the course of the work.

All the work on the program was coordinated by NASA, which was directly financed by Congress. To oversee the development of the Saturn launch vehicle at the U.S. Army's Redstone Arsenal, the Marshall Space Flight Center, under Wernher von Braun, was established, with a unique experimental base for test firings of rocket units and dynamic tests of the assembled launch vehicle. The center's staff in the peak period numbered 8,000 people.

Also established then was a special center (its construction was begun in 1961) for training astronauts. The size of that center's staff reached 5,000.

Selected as the leading firm for the Command and Service Module (CSM) in 1961 was North American [Aviation], and specified (in 1962) were the primary subcontractor firms, many of which had had experience working on the Mercury and Gemini programs.

The contract for the development of the lunar module was signed with Grumman Aircraft [Engineering Corporation] (which had specialized prior to that in the building of aircraft and helicopters) in 1962, after the final selection of the lunar mission profile.

NASA's budget as the operations on that program unfolded was characterized by the following figures (in billions of dollars): 1962: $1.9; 1963: $3.7; 1964: $5.7; 1965: approximately $6.0; 1966: $5.9; 1967: $5.7. As a result of those appropriations, a unique experimental base was established that American specialists consider to be a "great national asset." It took nearly five years to set up that base: about three years to design it, and about two years to build it.

Among the basic test stands that made up that base were the following:

1. The group of stands at Edwards Air Force Base for testing of the F-1 LPRE with a thrust of up to 700 tons per second.

2. The group of stands of the Rocketdyne Company in Santa Susana, which were equipped with steam-jet ejectors that developed a vacuum in the nozzle outlet section equivalent to an altitude of 18 km, for testing the J-2 LPRE of the rocket unit for the Saturn 5 launch vehicle's second stage (S-II).

3. The stand previously constructed at the Marshall Center for dynamic tests of the Saturn 5 rockets in a suspended configuration.

4. Two coupled stands at the NASA complex in Mississippi for preflight test firings of the rocket unit for the Saturn 5 launch vehicle's first stage (S-I), as well as the stand there for preflight tests of the S-II second stage's rocket unit.

5. The set of stands at the test base in Sacramento for preflight tests of the rocket unit for the third stage (S-IVB).

6. Space Launch Complex 39 at Cape Kennedy, where the Apollo/Saturn system was assembled in the Vehicle Assembly Building [VAB] and transported together with the launch platform in the vertical position to the launch pad.

Increasing the reliability of the operation of all the systems that were part of that most complex system was given special priority in the program. In the opinion of American specialists, that was ensured by the following:

—backup of individual components, units, and assemblies or entire systems and their careful selection, as well as extremely strict testing conditions

—especially painstaking ground-based system testing, which differed fundamentally from the methods for testing ballistic missiles (the latter was conducted basically during the flight design test process)

—making changes sequentially aimed at improving structural components and equipment and strict observance of the principle of increasing as much as possible the reliability of existing equipment

Ground tests were assigned such a large role for the following reasons. First, the unique planned ground experimental base (every possible kind of test stand, altitude chamber, simulator, trainer, and so on) made it possible to ensure the reliability of the Apollo/Saturn system primarily through ground-based testing. Second, the establishment of the ground experimental base required substantially smaller expenditures than would have manufacture and flight design tests, which, under the old methods of testing reliability, would have been needed in larger numbers. And third, during the ground-based tests, it was considerably easier to make measurements, their accuracy was enhanced, the objects being tested could be examined after the tests, and repeat tests could be performed.

Despite all that, of course, it was recognized that only during flight design tests would the system's components be operating under actual conditions. That is why the stages for the flight design testing of the components, assemblies, equipment and subsystems of the system also received a great deal of attention.

From 28 May 1964 through 30 June 1965, five prototypes of the Apollo's CSM were launched into Earth satellite orbits with the Saturn 1 launch vehicle.[2] In 1966, the Saturn-1B launch vehicle was used for two launches of the recovery capsule of Apollo's experimental CSM into a ballistic trajectory with a reentry at a velocity of 8 km/s. In that same year, a Saturn 1B rocket was launched to check re-ignition of the oxygen-hydrogen LPRE of the S-IVB stage.

The year 1967 saw the first unmanned launch of a Saturn 5 with an experimental Apollo CSM, into a ballistic trajectory, to check out the recovery capsule in a reentry at 11 km/s. In 1968, a similar launch was repeated. That same year, the lunar module (with the Saturn 1B launch vehicle) was tested in near-Earth orbit, after which the CSM, with a crew on board, was sent by the same launch vehicle into a satellite orbit, and, last of all, the Apollo CSM, with astronauts on board, was inserted into a selenocentric orbit by the Saturn 5 launch vehicle.

In early 1969, a Saturn 5 launch vehicle was used to insert a complete manned Apollo spacecraft into an Earth satellite orbit, with separation and independent flight by the lunar module.

In 1969, in the fifth launch of the Saturn 5, a complete Apollo spacecraft with crew was inserted into a circumlunar orbit, where the lunar module separated from the CSM, and a simulation of its landing on the Moon's

surface was carried out, with subsequent rendezvous and docking of the ascent stage with the CSM and transfer of the astronauts into the recovery capsule, in which they returned to Earth at escape velocity.

On 16 June 1969, in the sixth launch, the first lunar mission was performed on the Apollo-11 spacecraft. N. Armstrong and E. Aldrin stepped out onto the Moon's surface and, after performing the tasks set for them, safely lifted off in the lunar module's ascent stage, docked with the CSM, where M. Collins was waiting for them, and returned to Earth. In the period from 16 July 1969 through 7 December 1972, the United States successfully performed six (out of seven) missions; 12 American astronauts visited the Moon's surface. Because of financial difficulties stemming from the protracted war in Vietnam, the United States was forced to stop work on the Apollo/Saturn 5 program (initially, 10 missions had been planned).

The total spending for the program amounted to $24-26 billion. The cost of the lunar module that enabled the delivery of the astronauts to the Moon's surface and their return to the CSM was equal to the cost of 15 such modules made of gold. The cost of one carat of lunar soil delivered to Earth by the astronauts was three and a half times more expensive than a one-carat diamond.

The American program, which has already become history, is undoubtedly an outstanding scientific and technical achievement that cannot be passed over in silence.

We should have used that experience to perform more advanced missions to the Moon's surface.

How It All Began

S. P. Korolev and his associates understood that further improvement of space operations with manned spacecraft would require increasing the payload that could be inserted into near-Earth orbit. That could be done with either superheavy or medium launch vehicles. In the latter instance, docking in orbit would be required. In late 1961, S. P. Korolev's OKB was given the assignment of developing the N1 launch vehicle, which would insert a 40- to 50-ton payload into near-Earth orbit (the development time frame was 1962-1965), and the N2 launch vehicle, with a 60- to 80-ton payload (the development time frame was 1963-1970). Later, the time frames for the development of those rockets were pushed back repeatedly (for various reasons). In that same year, 1961, V. N. Chelomey's firm was assigned to work on a rocket-space system intended for circumlunar flight. The task of landing a mission on the Moon's surface had not been raised at all at that time. Thus, S. P. Korolev found himself, as it were, removed from the lunar program. In 1962, the plan was revised one more time. The objective was to concentrate forces and resources on the creation of a manned circumlunar flight system that would be based on the UR500 launch vehicle being developed by Chelomey's OKB. The work on the N1 launch vehicle was limited to the development of a conceptual design only.

In July of 1962, the expert commission under M. V. Keldysh examined that design, which had been worked out under such an uncertain circumstance, and concluded that it was necessary (and feasible) to develop a launch vehicle with a payload mass of 75 tons and a launch mass for the entire system of 2,200 tons. The flight design tests were expected to begin in 1965, provided that the launch site was built and placed into service by that time.

That same decision (postanovleniye) of the Academy of Sciences was supposed to define the objectives and produce a proposal for the development of space vehicles to be inserted into space by that launch vehicle. It is precisely during that period, during the development of the conceptual design, that dissension occurred between S. P. Korolev and V. P. Glushko. Korolev and his associates asserted the need to use high-power, non-toxic rocket fuel components (liquid oxygen, liquid hydrogen, and hydrocarbon fuels) in the rocket engines. V. P. Glushko insisted on such high-boiling-point, toxic components as nitrogen tetroxide and unsymmetrical dimethylhydrazine and, of the cryogenic components, liquid hydrogen and liquid fluorine. He rejected the idea of developing oxygen-kerosene and oxygen-hydrogen LPREs for the N1 launch vehicle. Sergey Pavlovich was forced to appeal to the aircraft engine general designer, N. D. Kuznetsov, who undertook the development of such LPREs, even though it did not correspond with what he had been doing. Kuznetsov had to develop test stands and perfect new technologies in his own OKB and at the plant where the engines were manufactured. The officials of the Kuybyshev region, whose plants manufactured the N1 launch vehicle and the engines for its rocket units, should be given their due (V. Orlov and V. Vorotnikov, CPSU Oblast Party Committee secretaries, and V. Litvinov, sovnarkhoz chairman). They did everything within their power to ensure the successful completion of the work.

It was only in mid-1964 (when the work on the Apollo/Saturn program was already broadly expanded) that it was decided that landing a mission on the Moon's surface was to be a high-priority objective.

Studies of different versions of such a mission had already been conducted in Korolev's OKB. At first, he showed a preference for a multiple-launch system assembled from components in near-Earth orbit. To a certain extent, that lunar mission profile had something in common with the work on the Soyuz program which was already being developed in the OKB. That program envisioned the docking of two manned spacecraft in near-Earth orbit and the transfer of cosmonauts from one craft to the other through open space. The United States, however, as has already been stated, had settled on the single-launch plan.

The American program nudged our country's highest leaders into issuing the assignment for the development of designs for launch vehicles that could support a lunar mission with a single launch. Such assignments, in addition to Korolev's firm, were also given to the OKBs headed up by M. K. Yangel and V. N. Chelomey. Their designs (the R56 and the UR700, respectively) were patterned on Glushko's engines.

By late 1964, Korolev's OKB had worked out a pre-draft plan for the N1/L3 lunar rocket system. It called for landing one cosmonaut on the Moon, while another cosmonaut would be in circumlunar orbit in a lunar orbiter, and they would return to Earth in a recovery capsule that would be part of the lunar orbiter. The mission would be performed with a single launch of the N1 launch vehicle. In order to do that, plans called for increasing the payload mass from 75 to 92 tons, and later to 95 tons (or more). Searches were undertaken for approaches that would ensure the insertion of such a payload without radical revision of the published technical documentation, the design of the rocket units, or the special-purpose manufacturing equipment. The following was proposed:

—increase the launch mass from 2,200 to 2,700 tons

—install six additional LPREs in the central unit of the first-stage rocket unit (in unit A)

—boost the LPREs of the propulsion systems of the rocket units of the first three stages (units A, B and V) by an average of 2 percent by introducing a "flexible" program for controlling the engines' thrust

—in the future, in the upper-stage rocket units, change to LPREs that have higher specific thrusts resulting from the use of liquid oxygen and hydrogen as their fuel

The N1 launch vehicle (Figure 7) had a unique layout and power plant configuration.

First, the fuel compartments of the A, B, and V rocket units contained suspended spherical tanks whose structures were subject only to loads from the the pressure associated with tank pressurization and the hydrostatic pressure of the column of liquid in them; the inertial loads and the engines' thrust were absorbed by the fuel compartment's load-bearing structure. For the first time in our country (and perhaps even in the world), prepumps [prednasosy] were used in the pumps of the turbopump assembly of the LPREs. Studies indicated that, with such a structural-power configuration, the mass of the fuel compartments could be smaller than with a design in which the fuel tanks themselves were load-bearing structures, as in the Saturn 5.

The structural components of the tanks and compartments were transported from the manufacturing plants to the space launch facility by ordinary railway transport. The Americans delivered the rocket units, assembled at the manufacturing plants, to the space launch facility on special barges via a specially constructed canal that, naturally, required large, additional expense.

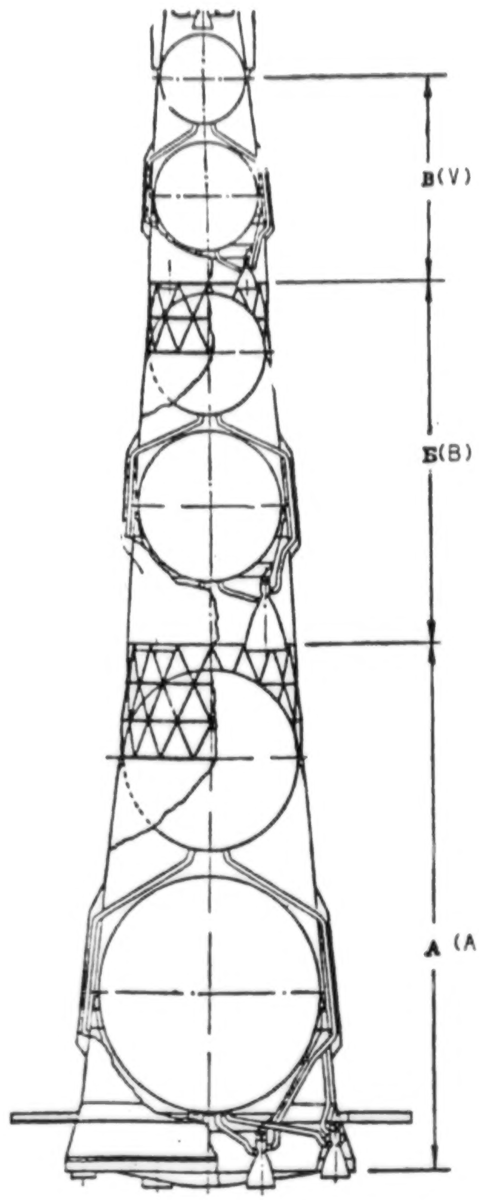


Figure 7. N1 launch vehicle. A, B, and V are the rocket units (published for the first time)

Second, the A, B and V rocket units were multi-engine units. For example, rocket unit A consisted of 24 peripheral and six central LPREs, with a nominal ground-level thrust of 154 tons. Installed in rocket unit B were eight LPREs with high-altitude nozzles with a nominal vacuum thrust of 179 tons, unit V had four engines, with a nominal vacuum thrust of 41 tons, which had the identical pneumatic schematic as in unit A's engines.

The size of a single LPRE in unit A was chosen on the basis of the condition of minimal expenditures for its

development and manufacture. In order to enhance reliability, plans called for the backup of individual LPREs. For example, the first stage could perform a flight with two pairs of opposing peripheral engines switched off; the second stage, with one pair; and the third stage, with one engine switched off.

In order to cut off malfunctioning engines situated opposite each other, a special system was provided for monitoring their operation (KORD). Unfortunately, that system was not able to react to the rapidly occurring processes (for example, those which precede the explosion in the turbopump assembly's oxygen pumps). But such defects would have been eliminated during the final development testing of the individual LPREs and checked for during those engine's delivery tests.

Third, control of the launch vehicle's first and second stages relative to the lateral axes (in terms of the pitch and yaw channels) was effected by mismatching the thrusts of the opposing, fixed peripheral engines, whereas control relative to the longitudinal axis (the roll channel) was effected with swivelling nozzles that were located along the periphery of the rocket units and through which was expelled the gas that is withdrawn behind the turbines of the turbopump for the individual peripheral engines. Control of the third stage was effected by swiveling its gimbal-mounted individual engines. All the individual LPREs had systems for delivering the fuel components into the combustion chamber with a turbopump assembly with afterburning of the working fluid behind the turbine. The engines operated on liquid oxygen and kerosene, and possessed power-to-mass ratios that were high for that time.

Unlike the Apollo/Saturn 5 system, the N1/L3 system was assembled and tested in the Assembly and Testing Building (on a special erector) in the horizontal position. The assembly of the lunar rocket system—the main unit—was performed in another building, the so-called Space Vehicle Assembly and Testing Building.

The lunar rocket system (LRK) consisted of the G and D rocket units, the lunar orbiter (LOK) with its rocket unit, the lunar module (LK), the emergency rescue system, and the nose fairing (Figure 8).

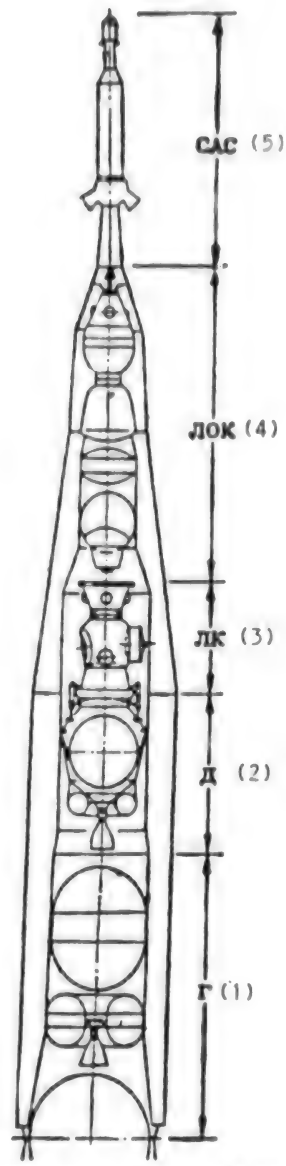


Figure 8. L3 lunar rocket system (published for the first time)

Key: 1. G rocket unit—2. D rocket unit—3. Lunar module—4. Lunar orbiter—5. Emergency rescue system

The G rocket unit with the oxygen-kerosene LPRE imparted to the LRK a velocity close to escape velocity (approximately 11.2 km/s), while the D rocket unit provided mid-course correction of the translunar trajectory, deceleration of the lunar orbiter and the lunar module, their injection into a circumlunar orbit, and primary deceleration during the lunar module's landing on the Moon. Acceleration of the orbiter from circumlunar orbit back to Earth and mid-course correction of its trans-Earth trajectory were provided by the I unit.

The lunar module was designed for one cosmonaut. The Ye rocket unit had an LPRE that operated on nitrogen tetroxide and unsymmetrical dimethylhydrazine. That engine was used for deceleration in the final leg of the descent trajectory (from an altitude of approximately 1 km), maneuvering of the lunar module during the landing on the Moon's surface, and the LK's subsequent ascent from the Moon's surface and rendezvous with the orbiter in circumlunar orbit. The orbiter played the role of the active craft during the docking. It should be noted that both craft had both a main engine and a backup engine.

The emergency rescue system enabled the rescue of the cosmonauts in emergency situations during lift-off and in the powered-flight phase for insertion of the lunar rocket system into near-Earth orbit. The nose fairing

provided protection from factors present during the powered-flight phase and was jettisoned during the operation of the second stage.

The assembled N1-L3 system was transported by two coupled diesel locomotives on two railroad lines from the Assembly and Testing Building to the launch facility where it was lifted into the vertical position.

If the lunar mission profile for the Apollo-Saturn 5 program were to be compared with our profile, then one would have to admit that the Americans' profile had the better characteristics. Their profile delivered three astronauts to lunar orbit, ours, two. Theirs landed two men on the Moon's surface, ours, one. Because the Saturn second and third stages used liquid hydrogen and because the location of the U.S. space launch facility at Cape Canaveral was more favorable than our cosmodrome's location at Baykonur (from the standpoint of using the Earth's rotation in launches in an easterly direction), the Saturn 5 launch vehicle could insert into near-Earth orbit a payload 10% larger with a virtually identical launch mass. Third, the Apollo-Saturn System had one less rocket stage than did our N1-L3 system and, consequently, it was simpler and, in theory, had a higher level of reliability. And finally, the Americans introduced procedures that increased the reliability of the operation of the rocket units' propulsion systems by requiring their preflight holddown firing tests and delivery for final assembly without overhauling. The incorporation of those procedures required a great deal of money for the construction of special test-firing stands. And that money was appropriated.

S. P. Korolev and his associates understood all that. But in the situation that existed, they were limited in time, allocated money, and production capacities. So they did not adopt that way of doing things. The fundamental factor in the decision-making process was the desire to beat the United States in landing a mission on the Moon with a minimum of expense.

Unfortunately, as it can be seen from what was said earlier, our country, unlike the United States, was developing two programs independent of each other, one of which involved a manned circumlunar flight, the other, the landing of a mission on the Moon's surface. For the second program, as has also been mentioned, three launch vehicle designs were being developed (N1, R-56, and UR-700). In the United States, however, all efforts were directed at the execution of the one Apollo-Saturn program that had received nationwide support. A circumlunar flight by astronauts (with their return to Earth) was envisioned only as a stage in landing a mission on the Moon.

S. P. Korolev made repeated attempts to consolidate both our programs or to at least use the developments of one for the other as much as possible. The first attempt was made in 1961, when he proposed using the N1 (the first version, but with a 75-ton payload mass) sending two cosmonauts around the Moon and landing them on Earth in a recovery capsule entering the atmosphere at escape velocity.

He made a second attempt in 1964, when, for that same purpose, he proposed using a rocket consisting of the upper rocket units B, V and G and the lunar module from the N1/L3 system. But all such attempts failed.

In the second half of 1965, it became clear that the collective of the OKB headed by V. N. Chelomey would not be able to ensure that our country would be first place in achieving a manned circumlunar flight, because the work was lagging in the development of the circumlunar flight system. Sergey Pavlovich proposed that the D rocket unit and the lunar orbiter from the N1/L3 system be used for that purpose. After long and heated discussions at meetings with the chairman of the USSR Council of Ministers' Military Industrial Commission, L. V. Smirnov, and with the minister of general machine building, S. A. Afanasyev—meetings that ended in both sides blaming each other—the proposal was adopted after all.

Thus, born at the end of 1965 was the UR-500K-L1 program, which envisioned a circumlunar flight by two cosmonauts with their return to Earth in a recovery capsule at escape velocity. The lift-off from Earth was supposed to be effected by the UR500K (Proton) launch vehicle with the D rocket unit. The manned spacecraft (it was given the "designation" 7K-L1), as has already been stated, was based on the lunar orbiter from the N1-L3 program (figures 9 and 10). S. P. Korolev became responsible for the realization of the UR500K-L1 program.

One should note the large role played by Korolev in establishing the ground services, whose importance in controlling manned craft in space is extraordinarily great. The creation of those services was already under way by the time of the launches of the unmanned space vehicles. S. P. Korolev saw the prospects for the use of computers in a space vehicle's motion control system. His OKB was one of the first to use computers, first for conducting analyses involving, for example, ballistics, strength, and aerodynamics and, later, in space vehicle motion control systems on a real-time basis.

Within a short time there was set up a network of telemetry monitoring stations for receiving telemetry and trajectory information and transmitting it via reliable noise-immune communications channels to a computer coordination center that processed the information and, in a form suitable for decision making, transmitted it to the Flight Control Center. On the basis of those recommendations, the Flight Control Center made decisions and issued commands to the probes or spacecraft. The Flight Control Center had two-way communications with manned space vehicles.

It can be seen from what has been stated that, as early as in the early 1960s, S. P. Korolev had to deal with

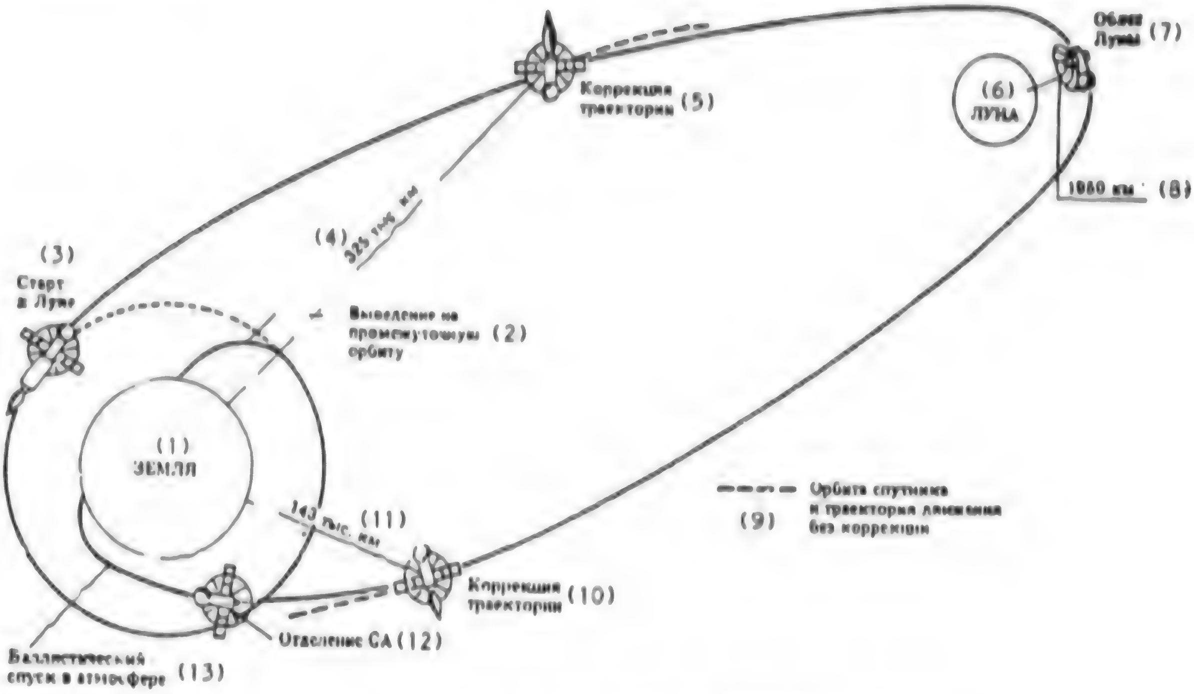


Figure 9. Circumlunar mission profile for UR500K-L1 program

Key: 1. Earth—2. Insertion into parking orbit—3. Translunar injection—4. Distance of 325,000 km—5. Mid-course correction—6. Moon—7. Circumlunar flight—8. Distance of 1,950 km—9. Satellite orbit and trajectory without correction—10. Mid-course correction—11. Distance of 143,000 km—12. Separation of recovery capsule—13. Ballistic descent in the atmosphere

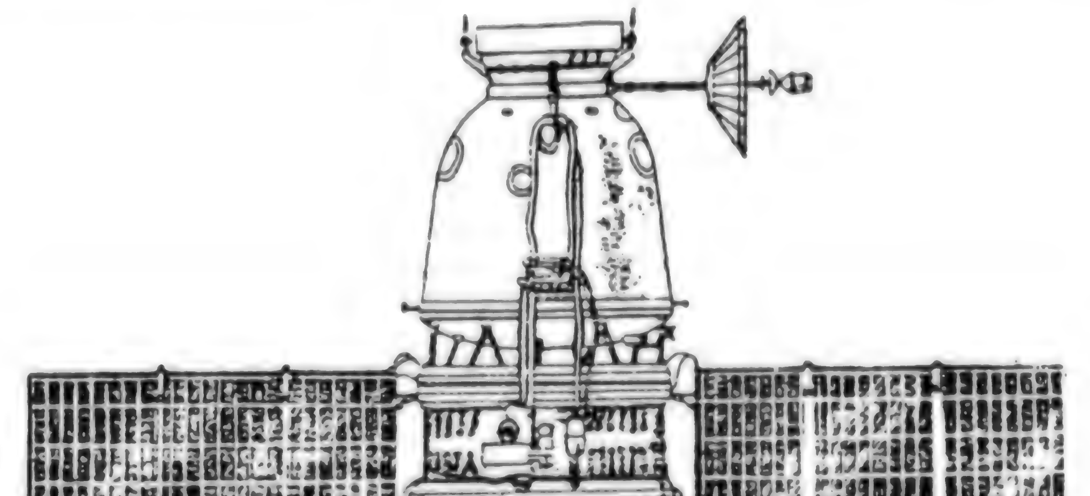


Figure 10. Design of 7K-L1 craft for UR500-L1 system

complex technical systems whose development and use involved numerous collectives of specialists of varying professional orientation

Without Korolev

After S. P. Korolev's death on 14 January 1966, there remained for his collective the following tasks, conceived and begun, but not completed, by him

1. Final development, ground testing and execution of docking of two manned spacecraft, with the transfer of cosmonauts through open space from one craft to the other (the Soyuz program)

2. Final development, ground testing, and execution of a circumlunar flight by two cosmonauts, with their return to Earth in a recovery capsule at escape velocity (the UR500K-L1 program)

3. Final development, ground testing and execution of the landing of a single cosmonaut on the Moon, his return to the orbiter waiting for him in lunar orbit with the other cosmonaut, and their return to Earth in a recovery capsule at escape velocity (the N1/L3 program, Figure 11).

In addition to that work, the OKB also had other work to do associated with previously received orders (for example, work on the a rocket-space system, the Molniya-1 satellites, and so on).

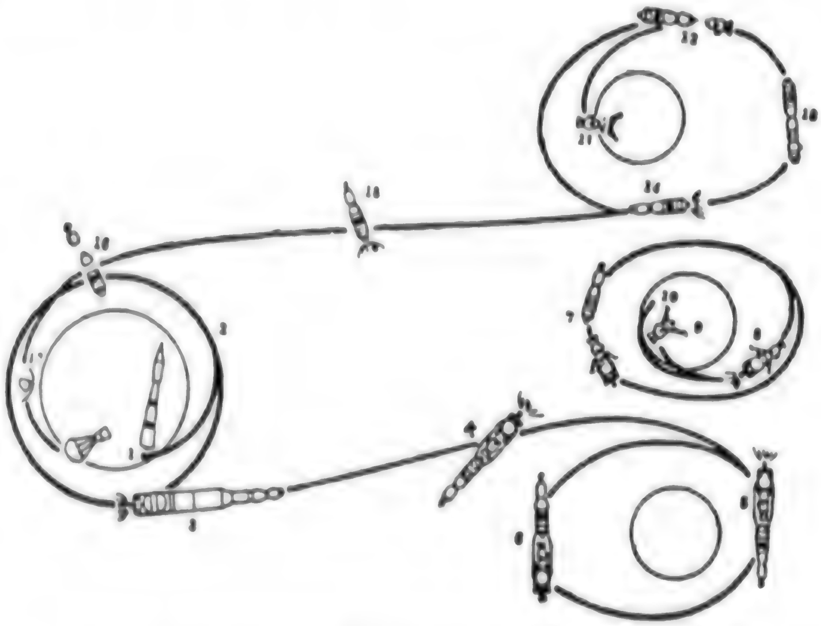


Figure 11. Profile for the N1/L3 program's manned lunar mission

Key: 1. Lift-off from Earth with two cosmonauts on board—2. Insertion of L3 system into low near-Earth orbit after N1 launch vehicle's A, B and V rocket units cease operation—3. Orientation and firing of G rocket unit's engine at designated point in orbit, insertion of L3 system into translunar trajectory, separation of spent G unit, and jettison of lower and middle adapters of D unit—4. Leg for performing course corrections with D rocket unit's restartable engine—5. Insertion into lunar orbit with D unit's engine—6. Transfer of one cosmonaut via open space from descent vehicle of the lunar orbiter (LOK) to the cabin of the lunar module (LK)—7. Separation of LOK from the LK-plus-rocket-unit-D assembly, jettison of upper adapter and deployment of LK landing struts—8. Final firing of D unit's engine for operation in deceleration phase during Moon landing, burnout of D unit and its separation from LK at altitude of approximately 1 km above Moon's surface, firing of LK's engine for deceleration in final phase of Moon landing, and execution of landing maneuver—9. Landing on Moon, emergence of cosmonaut onto surface, televised report, and return to LK's lunar cabin (length of stay on Moon, 4 hours)—10. Point of impact on Moon of spent D rocket unit—11. Re-ignition of LK's engine for ascent from Moon and undocking of LK's ascent module from landing module—12. Insertion of LK's ascent module into region for docking with orbiter—13. Docking in lunar orbit of the two manned spacecraft, transfer of cosmonaut via open space from LK to LOK and undocking of LK—14. Firing of "I" rocket unit's engine at designated point in lunar orbit and insertion of LOK into trans-Earth trajectory—15. Leg for performing course corrections with "I" rocket unit's engine—16. Separation of recovery capsule with the two cosmonauts—17. Controlled reentry phase, with two entries into atmosphere [skip-glide technique]—18. Triggering of parachute system, and soft landing in designated region

It is evident from what has been stated that the volume and complexity of the work facing the OKB after the unexpected death of its director had increased substantially. The competition for first place in space was continuing. The work in that field was being developed primarily for prestige purposes and was directed or was in the field of view of our country's highest leaders.

Since rocket-space technology represented the leading edge of scientific and technical progress, it, before the other sectors of science and technology, felt all the "charms" of that period's command-bureaucratic style of leadership.

Despite that, S. P. Korolev's successors did everything within their power to complete the projects conceived by him.

The Soyuz spacecraft played a large role in the circumlunar flight program. The testing for the circumlunar flight program was performed on an unmanned version of that craft, which was called Zond (see below).

The work on the Soyuz program, despite the tragic outcome of the Soyuz-1 launch, which ended in the death of Cosmonaut V. Komarov, was performed in its entirety. The cause of the cosmonaut's death had nothing to do with the functioning of the new systems and assemblies incorporated into the Soyuz (systems and assemblies that were new by comparison of those of the Vostok and Voskhod ships) and certainly nothing to do with the docking system. That work has been illuminated in rather broad detail in the open press, and I will sum up some of its results.

Dockings were performed between the Kosmos-186 and Kosmos-188 unmanned space vehicles, launched on 27 and 30 October 1967, as well as between the Kosmos-212 and Kosmos-213 vehicles, launched on 14 and 15 April 1968. The latter two were identical to the manned Soyuz spacecraft. Then, Soyuz-4 (Cosmonaut V. Shatalov) and Soyuz-5 (cosmonauts B. Volynov, A. Yeliseyev and Ye. Khrunov) docked. After the hard docking, cosmonauts A. Yeliseyev and E. Khrunov transferred from one craft to the other by means of a spacewalk.

Later, there was the successive launching of Soyuz-6 (with cosmonauts G. Shonin and V. Kubasov), Soyuz-7 (with cosmonauts A. Filipchenko, V. Volkov and V. Gorbatko) and Soyuz-8 (with cosmonauts V. Shatalov and A. Yeliseyev).

With the launch on 1 June 1970 of Soyuz-9, with cosmonauts A. Nikolayev and V. Sevastyanov, and their 18-day stay in near-Earth orbit, the initially planned program came to an end.

The work on that program was developed further in the international Apollo-Soyuz project and the Salyut long-duration orbital station. Those programs opened up the way for the development of space complexes of greater complexity that use the docking of component modules to perform assigned tasks.

The work in the UR500K-L1 program, in my opinion, was also successfully completed. In the open press, it was known as the launches of the Zond-4 through -8 unmanned space vehicles. In actuality, however, as has been noted, they were launches, carried out by the UR500K launch vehicle with the D rocket unit, of unmanned space vehicles analogous to the 7K-L1 manned spacecraft, but without cosmonauts.

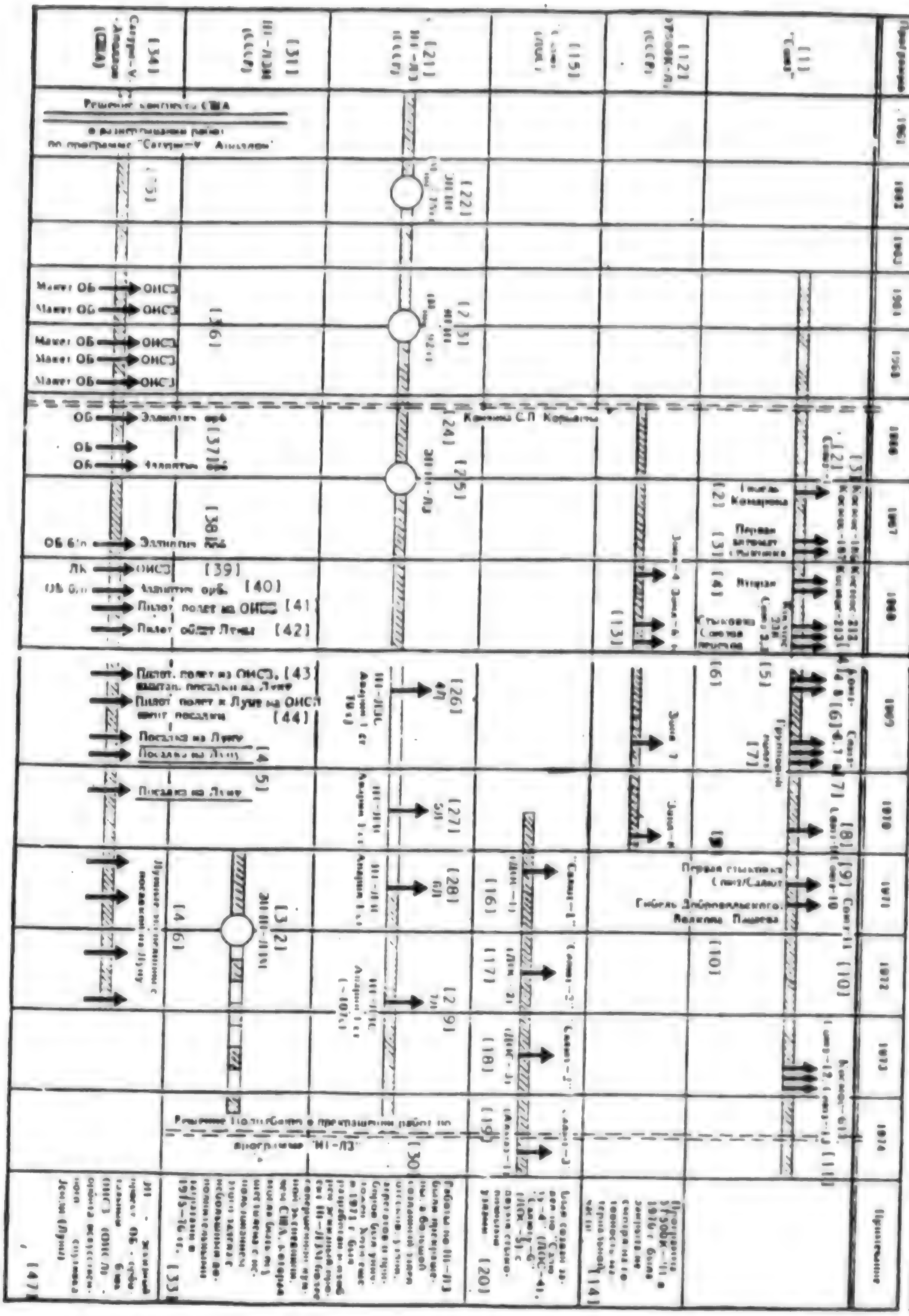
Zond-4, launched on 2 March 1968, failed in its mission of a circumlunar flight because of a failure of the attitude control system.

Completed with the launch of Zond-5 (on 15 September 1968) was a circumlunar flight and the return of the recovery capsule at escape velocity along a ballistic trajectory into the waters of the Indian Ocean. Launched on 10 November 1968 and 8 August 1969 were Zond-6 and -7, respectively, whose recovery capsules, after a circumlunar flight, returned to Earth at escape velocity, making a controlled reentry with a skip-glide technique that used the capsules' aerodynamic lift. The touchdowns of those recovery capsules were accomplished in a designated region of the Soviet Union's territory.

Launched on 20 October 1970 was Zond-8, which made it possible to perfect a version for the return of a recovery capsule to Earth with a controlled reentry that used aerodynamic lift. The trajectory for the circumlunar flight and the return to Earth, which was tried out during that flight, was more advantageous in terms of power consumption and ensured a more precise splashdown, which substantially facilitated the search-and-rescue operations. This last launch was conducted in the interests of the N1/L3 program.

The Moon and the Earth were photographed from various distances on all the flights. High-quality black-and-white and color photos were obtained as a result. The efficiency of all the systems associated with the cosmonauts' vital activities and safety during a circumlunar flight and during their return to Earth was checked.

But, as a result of a decision by the higher authorities, the circumlunar flight by two cosmonauts in the UR500K-L1 program did not take place, despite the fact that the material base and the cosmonauts for the flight were ready. This decision resulted from the fact that the United States had already taken the lead from us in that direction. I feel that the decision was erroneous and that it did not take into consideration the opinion of the rank-and-file people and specialists who had labored heroically to execute the program; nor did it take into consideration the need for those launches in the further development of rocket-space technology.



Key: 1. Soyuz—2. Soyuz-1, death of Komarov—3. Kosmos-186/Kosmos-187 [sic], first automatic docking—4 Kosmos-212/Kosmos-213, second automatic docking—5. Kosmos-238, Soyuz-2, Soyuz-3—6. Soyuz-4/Soyuz-5, docking of Soyuzes, transfer of cosmonauts—7. Soyuz-6/Soyuz-7/Soyuz-8, group flight—8. Soyuz-9 flight—9 Soyuz-10 flight, first Soyuz/Salyut docking—10. Soyuz-11 flight, deaths of cosmonauts Dobrovolskiy, Volkov, and Patsayev; 11. Kosmos-613 and Soyuz-12 and -13 flights—12. UR500K-L1, USSR—13. Zond-4, Zond-5, Zond-6 flights—14. The UR500K-L1 program was closed down in 1970, despite the fact that the material base was ready—15. Salyut long-duration orbital station (DOS)—16. Salyut-1 (DOS-1)—17. Salyut-2 (DOS-2)—18. Salyut-2 (DOS-3)—19. Salyut-3 (Almaz-1)—20. A large stock of completed research was ammassed from Salyut-4 (DOS-4) and Salyut-6 (DOS-5) with its two docking ports—21. N1/L3, USSR—22. N1/L3 CD (eskiznyy proyekt) [see item No 47] with payload mass of approximately 75 tons—23. N1/L3 CD with payload mass of approximately 92 tons—24. S. P. Korolev's death; 25. N1/L3 CD—26. 4L, N1/L3S, 1st stage accident (70 seconds)—27. 5L, N1/L3S, 1st stage accident—28. 6L, N1/L3S, 1st stage accident—29. 7L, N1/L3S, 1st stage accident (approximately 107 seconds)—30. Politburo decision to stop work on the N1/L3 program—31. N1/L3M, USSR—32. CD of N1/L3M—33. Work on the N1/L3 was stopped, and the amassed stockpile of compartments, units, assemblies and instruments was destroyed. That was done even though the conceptual design had been worked out and approved back in 1971 for the N1/L3M, which was a more advanced version of a lunar mission than that of the United States and which could have been carried out with that stockpile with only a small increase in spending in 1975-1976.—34. Apollo/Saturn 5 Program—35. Decision of the U.S. Congress to begin operations on the Apollo/Saturn 5 program—36. Flights of OVs [see item No 47] in ESOs [see item No 47]—37. Flights of OVs in elliptical orbits—38. Flight of OV without crew in elliptical orbit—39. Flight of lunar module in ESO—40. Flight of OV without crew in elliptical orbit—41. Manned flight in ESO—42. Manned circumlunar flight—43. Manned flight in ESO, simulation of Moon landing—44. Manned flight to Moon in LSO, simulation of landing—45. Moon landings—46. Lunar missions with Moon landings—47. CD—conceptual design [R. eskiznyy proyekt - "draft plan"]. OV—orbital vehicle. ESO (LSO) Earth (lunar) satellite orbit

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At the same time that the decision was made to stop work on the UR500K-L1 program, a decision was made at the urging of D. F. Ustinov, the then-CPSU Central Committee secretary for industry, that our OKB should develop a long-duration orbital station tended by crews delivered by manned Soyuz spacecraft modified for that purpose.

The permanent orbital station, subsequently called Salyut, was launched by the UR500K launch vehicle. The Salyut's frame was based on that of the Almaz orbital station, which had been in development over a long period of time by V. N. Chelomey's OKB.

The decision made no sense to me then (and it still makes no sense to me now), inasmuch as the work on the Almaz orbital station was being done at the same time that work was being done on Salyut, and our OKB was also charged with developing yet another modified version of the Soyuz craft, which was intended for visiting the Almaz station.

The decision could not help but complicate our relations with V. N. Chelomey, which were already strained because of the transfer to us (while Sergey Pavlovich was still alive) of subsequent work on the circumlunar flight. Naturally, the decision increased our OKB's workload substantially and could not help but affect the progress of the work on the N1/L3 program.

The first Salyut was inserted into near-Earth orbit on 19 April 1971 (less than a year after the assignment had been received). In mid-1972, an attempt was made to orbit a second Salyut. It ended in failure.

A third station (called Salyut-2) was inserted into near-Earth orbit in April of 1973, but, because of the failure of the attitude control system, it was "dumped" into the waters of the Indian Ocean.

The Almaz-1 orbital station went into near-Earth orbit in late June 1974, under the name of Salyut-3. Soyuz-14, with cosmonauts P. Popovich and Yu. Artyukhin, docked with it. In January 1975, that station was removed from orbit because of problems that had arisen in it. The fourth permanent orbital station (Salyut-4) remained in orbit nearly two years. Soyuz-17—with cosmonauts A. Gubarev and G. Grechko, who remained aloft nearly 30 days—and Soyuz-18—with cosmonauts P. Klimuk and V. Sevastyanov, who stayed for nearly 63 days—docked with it.

Salyut-5 was the name given to the Almaz-2 orbital station, which was inserted into orbit on 22 June 1976. Soyuz-21 (with cosmonauts V. Zholobov and B. Volynov), Soyuz-23 (with cosmonauts V. Zudov and V. Rozhdestvenskiy, whose docking was not a success), and Soyuz-24 (with cosmonauts V. Gorbatko and Yu. Glazkov) docked with it. After that, work on the manned orbital stations was stopped.

The next Salyuts (6 and 7), each equipped with a second docking port and a consolidated propulsion system, served as a base for the expansion of international cooperation in the field of manned space flights and the development of the Mir permanent orbital stations, with six docking ports.

The question arises as to who needed the duplication of work on the development of the orbital stations? It would have been wiser to combine the efforts of both OKBs to develop a unified orbital station and to entrust that work to N. V. [sic] Chelomey's firm, which had long been working on that area. Such a decision would have

relieved the burden being carried by our OKB substantially and would have given us the opportunity to concentrate our efforts on the work on the N1/L3 program.

The adoption of a decision on whether to carry out the N1/L3 program had clearly been dragged out. A decree (postanovleniye) on the N1/L3 program did not appear until 4 February 1967. It was titled "On the Progress of the Work on the Development of the UR500K-L1," and it proposed that the work begin on developing the L3 lunar rocket system. The date for starting the flight design tests was set by that decreee for the third quarter of 1967, and the execution of the lunar mission, for the third quarter of 1969.

In November 1967, the dates for the start of the flight design tests were moved back to the third quarter of 1968, while the dates for the execution of the lunar mission were supposed to ensure our country's priority over the United States. But by then, it was already clear that the dates set by these directives were unrealistic. They were not backed up by funds, or production capacities, or resources.

Our country could not afford to spend the kind of money that was spent by the United States for the Apollo/Saturn program. By 1 January 1971, the total spending for the N1/L3 program (or more accurately, the amount written off for that program) was 2.9 billion rubles [R]. The largest financial "infusion" did not occur until 1970 (around R600 million). But even those funds, allocated directly to the ministries, were being spent at their direction, without controls. The monopolistic practices of the departments, about which everyone is talking today, were already in full flower at that time. There were serious shortcomings both in the organization and in the coordination of the work in that program. Overall supervision of it was carried out by CPSU Central Committee Secretary D. F. Ustinov through the USSR Council of Ministers' Military Industrial Commission (L. V. Smirnov, chairman), to which only the defense-related sectors of industry were accountable. Meanwhile, nearly 500 enterprises from 26 departments were participating in the work on the N1/L3 program. Those enterprises would fail to meet the deadlines for deliveries of components to the "head" ministry (General Machine Building) and its "head" OKB (ours), which were responsible for completing the work on the program within the designated time frames. We did not have any levers of influence on our own suppliers. In a word, the organization of the work on the N1/L3 program was typical of the "period of stagnation" of our society.

All of this resulted in the United States beating us in landing a mission on the Moon and returning it to Earth.

How did the work go on the N1/L3 program?

Between February 1969 and December 1972, there were four launches of the N1 launch vehicle with the L3S upper stage (the mockup lunar module). They all ended in failure. During the first launch (on 21 February 1969), there was a fire in the rocket's tail section, and the A rocket unit's propulsion system was cut off by the KORD system at 70 seconds into the flight. The second launch (on 3 July 1969) was ended by the explosion of an oxygen pump from one of the A unit's engines, which was followed by the explosion of the entire rocket, which caused a great deal of destruction to the launch pad. The third launch took place on 27 July 1971 and also eneded in failure as a result of loss of the rocket's controllability in the roll channel. The fourth launch, conducted on 23 December 1972, turned out to be more successful. The flight lasted 107 seconds and ended with an explosion in the tail section of the A unit.

Those very first launches revealed that a multiengine power plant like the A unit's 30-engine system was inadequate. The LPREs intended for such systems had to have substantially greater margins of efficiency both in terms of output characteristics and in terms of useful operating life. But those margins, unfortunately, had not been stipulated in the initial technical tasking for development of the engines. That shortcoming could have been uncovered prior to the flight tests if test-stand firings of the assembled A stage had been conducted. That would have required the construction of a special stand, but the funds and capacities for such construction had not been provided, to save money. As the progress of the work on the N1/L3 program showed, such a stand was vitally necessary.

The technical tasking for development of the engines for the N1 launch vehicle were revised after the second launch and were coordinated with the those of the scientific research institutes of the sectors of industry involved. The OKB headed by N. D. Kuznetsov modified the engines and conducted test stand firings, and the manufacturing plant began delivering them for the assembly of the rocket units.

Despite their unsuccessful outcomes, the launches that were conducted solved a large number of problems specified for the first stage of the flight-design tests, and they made it possible to identify isolated shortcomings of the launch vehicle's systems and assemblies and to outline the necessary measures for their elimination.

An industrial production base (a cooperative system of manufacturing plants) was established, the technology was developed and assimilated, and the production of large-scale structural components of the rocket units was set into motion, along with their transportation to and assembly at the cosmodrome. A great many units, assemblies, systems and structural components of the rocket units were stockpiled for seven launch vehicles and stored in a special location, including two completely assembled rocket units (without the engines) in assembly jigs of the Assembly and Testing Building. For those units, delivery began of new individual LPREs that had undergone interdepartmental tests.

To put it briefly, the technology for preparing the N1/L3 system for launch had been mastered, as had the actual lift-off itself. That means that the mating of the launch

vehicle's on-board systems and assemblies had been checked both with the L3 lunar rocket system and with the integrated complex of ground equipment that had been set up.

The feasibility of controlling the rocket-space system's first stage in the pitch and yaw planes by mismatching the engines situated opposite each other had been proven, while, with respect to the longitudinal axis, control had been accomplished by swiveling the nozzles that expel the gas that is drawn off behind the turbines of the individual peripheral LPREs. The operation of the system for controlling the launch vehicle's motion in the first (the most difficult) atmospheric powered-flight phase had been checked. At the same time, the system for controlling the operation of the individual LPREs mounted in the A rocket unit, a system that was supposed to increase the level of reliability of the multiengine system via the cut-off of the individual backup LPREs, did not justify the hopes placed on it. It was unable to react to the rapidly occurring processes that would precede the destruction of an individual LPRE (such as the explosion of the turbopump assembly's oxygen pumps). In general, as has already been noted, those kinds of problems in the LPREs should have been eliminated by the appropriate ground firing tests. But a control system should be not just a controlling system, but also a predictive system and should cut off an engine before it fails, so that it cannot destroy a functional engine located next to it.

Back at the end of the 1960s, when it was clear that the United States was passing us in the work on landing a mission on the Moon's surface, our OKB began studying versions of a lunar mission with substantially better characteristics than those of the American version. We finally managed to get technical tasking from the USSR Academy of Sciences for a lunar mission with a list of the problems that it was supposed to solve. It must be noted that no such specifications had ever been received from the academy for the first version of the mission.

Studies were pursued in two directions: (1) a two-launch profile with N1 launch vehicles and with docking in circumlunar orbit of the components of the lunar system (Figure 12); (2) a more advanced launch vehicle that used liquid hydrogen and oxygen in the upper stages and was intended for a single-launch mission was being designed. Technical tasking for that rocket's engines were given to the OKBs headed by chief designers A. M. Isayev, A. M. Lyulka, and N. D. Kuznetsov while S. P. Korolev was still alive. But, for both those directions, it was necessary to continue the work on the N1 launch vehicle. One of the main problems was bringing the reliability of the individual LPREs for the A and B rocket units up to the needed level, thereby ensuring the output characteristics defined by the specifications.

The difficulties encountered during the modification of those LPREs, which were accompanied by repeated failures to meet delivery deadlines, generated in a certain circle of people (primarily, leaders such as D. F. Ustinov, L. V. Smirnov, S. A. Afanasyev) the opinion that N. D. Kuznetsov, given the existing attitude of the leadership of the Ministry of the Aviation Industry toward that work, would not be able to bring the engines up to the specified level of reliability any time soon, and, consequently, there would be neither an N1 launch vehicle nor its modified versions.

Because of that, and also because of the fact that the United States had already passed us in terms of flights to the Moon, the decision was made to stop work not only on the lunar mission, but also on the N1 launch vehicle. Placed on the agenda was the task of developing a reusable space transport system (like the Space Shuttle) with an oxygen-kerosene LPRE with a thrust of 700-800 tons, which was proposed by V. P. Glushko. He had managed to convince D. F. Ustinov and other leaders of the wisdom of doing so. At one time (after 1961), V. P. Glushko had rejected oxygen-kerosene and oxygen-hydrogen LPREs. In his monograph "Khimicheskiye istochniki energii" [Chemical Sources of Power], he wrote that "liquid oxygen is nowhere near the best oxidizer, and liquid hydrogen will never be of any practical use in rocket equipment." Life proved that assertion by V. P. Glushko to be wrong, and he had to revise his opinions and begin developing a high-thrust oxygen-kerosene LPRE.

As has already been stated, V. P. Glushko, 10 years earlier, had refused to develop such an engine, and Sergey Pavlovich had turned to N. D. Kuznetsov with the proposal. V. P. Glushko had spoken very negatively about the LPRE developed by N. D. Kuznetsov's OKB, even though that engine had characteristics that were better than those of the one developed earlier under V. P. Glushko himself (more than 14 years had been needed for the completion of the latter).

Over the course of just a few years, N. D. Kuznetsov had managed to bring the operating time of his own LPREs up to 10,000-12,000 seconds without removing it from the test stand—while the needed time for their operation during a flight did not exceed 140 seconds. The decision about stopping the work was unexpected and hasty and was made without consultation with the principal people doing the work. To this day, the chief developers of the N1 launch vehicle—our OKB and that of N. D. Kuznetsov—consider the decision about stopping the work on that rocket to have been a big mistake. Why was it necessary to forbid the launches of two almost fully assembled launch vehicles with the new LPREs? Their launches would not have interfered with work in new areas, since they had been begun more than two years earlier. And the experience attending the launch of those two vehicles would have yielded valuable material for new projects as well. It was also difficult to explain the correctness of the decision to destroy the stockpile for seven sets of launch vehicles to those specialists, through whose labor they had been created.

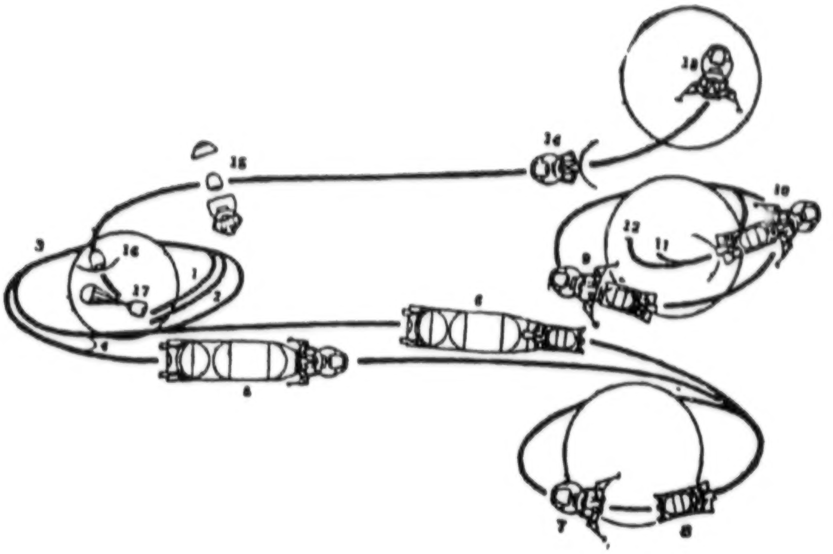

Figure 12. Two-launch mission profile for N1/L3 system

Key: 1, 2. Insertion trajectories of the two upper stages [golovnoy blok] (GB-1, with a mass of 104 tons, and GB-2, with a mass of 103 tons) with two N1 launches—3. Near-Earth parking orbit—4. Acceleration phases for the units from near-Earth orbit and their translunar insertion—5. GB-2 (consisting of manned lunar module and rocket unit) on translunar trajectory—6. GB-1 (consisting of two rocket units) on translunar trajectory—7, 8. Lunar module and rocket unit from GB-1 in circumlunar orbit—9. Assembly in that orbit of lunar module and rocket unit to form lunar landing system—10. Main deceleration phase during landing on Moon, in which the rocket unit's engine operates—11. Landing on Moon of the craft, whose mass at that moment amounts to 23.7 tons—12. Impact region on Moon's surface for spent rocket unit—13. Extended stay (five-14 days) on Moon's surface of lunar module with cosmonauts (three or two individuals, respectively)—14. Direct insertion of lunar module's ascent stage from Moon's surface into trans-Earth trajectory (the craft's mass at the moment of lift-off from Moon is approximately 19.5 tons, and its mass during the return to Earth is approximately 8.4 tons)—15. Separation of recovery capsule from module prior to reentry—16. Phase of controlled reentry into Earth's atmosphere—17. Deployment of parachute system and landing in designated region

And So, the Result

Could we have landed cosmonauts on the Moon's surface before the United States? Why did we not perform such a mission even after that? It seems to me that the time has come to answer those questions directly and clearly.

The answer to the first question is that we could not have beat the Americans. And here is why.

First, the United States at that time possessed higher scientific-technical and economic potentials than our country did.

Second, in the United States, the Apollo/Saturn program was a national, first-priority program that was supposed to restore the country's prestige. The U.S. government, enjoying the support of all the people in that matter, was able to appropriate the material and financial resources needed to carry out that program. We, however, could not allocate such assets.

Third, bewitched by the first (and undisputable) successes in space (the launches of the first Soviet satellites, Yu. A. Gagarin's flight, and so on), we underrated the challenge issued by U.S. President J. Kennedy in 1961. In our country, prior to 1964, we did not pay proper attention to the work on the landing of a lunar mission. N. S. Khrushchev gave priority to the work of Chief Designer V. N. Chelomey on a circumlunar flight (without a landing on the Moon's surface), which was based on the UR500 launch vehicle developed by him and later called the Proton launch vehicle.

In the United States, there was no separate circumlunar flight program. The circumlunar flight by American astronauts was planned from the very start as a stage in the work to send a mission to the Moon's surface. All the United States's efforts were aimed at the fulfillment of the unified Apollo/Saturn program.

Fourth, we underestimated the scientific and technical difficulties of accomplishing such a mission. Thus, we particularly underestimated the importance of ground

testing the rocket-space system, which required establishing a costly experimental base that would include stands for test firings of the rocket units' propulsion systems. Moreover, we did not have the money for developing such a base.

All those reasons, and others associated especially with the features of that period in our country's history, worked relentlessly against our performing a lunar mission and put us behind the United States in that area.

But we could have and should have performed such a mission after the United States did! Is it really so important that the Americans beat us in the execution of a lunar program? There are always period in science and technology when someone surges ahead and someone else lags behind. We should have used the Americans' experience (just as they did, when they used the experience we had garnered in launching the first satellites and the first person into space) to perform a more advanced lunar mission. And our country could have done that—even with the then-limited capabilities—if the then-leaders had listened to the opinions of the specialists and scientists who had developed the N1/L3 program. As early as 1971, we had already set forth our proposals for improving the characteristics of the lunar mission. In early 1972, a detailed plan had been worked out for an improved N1/L3M lunar program, which had been approved by all the chief designers and scientists involved in the development, including Chief Designer and Academician V. P. Glushko (their signatures are on the resolution of the Council of Chief Designers). That program called for the unique, single-craft, two-launch profile for landing three Soviet cosmonauts in any region of the lunar surface, where they would stay for up to 14 days (with a subsequent increase up to 30 days), with a direct return to Earth from the Moon's surface at any time. That mission could have been carried out in 1978-1980. Unfortunately, the program was not adopted, and all work on the N1/L3 program was stopped.

Guided by considerations of immediate prestige, the then-leadership of the rocket-space industry succeeded in proving to the higher authorities the necessity of stopping the work on the N1/L3 program and expanding the work on developing a reusable transport system. That decision was a major mistake. The creative labor of many thousands of people should not be wiped out so easily and freely, without any consideration of their opinion on the matter. The work of large collectives and the enormous material assets—all spent for nothing. There are lots of original design and production approaches in the N1 launch vehicle that are still of interest today. All that work could have been used also for the reusable transport system, which would have saved money and time spent irresponsibly on the new development which has become known as the Energiya-Buran system, the wisdom of whose use for the exploration of space is debatable.

The question is often asked, What would have happened with our space hardware if Korolev had still been alive?

I believe that even he, with his authority and persistent and focused nature, would not have been able to withstand the processes that encompassed all the spheres of activity of our society. It would have been difficult for him to work without enjoying support from the leaders of rocket-space technology in our country, who were pursuing (even while Sergey Pavlovich was alive) a policy that was incomprehensible in that regard. Undoubtedly, he would have achieved something. We would have been able to fly to the Moon and return to Earth, but, unfortunately, not within time frames that would have ensured our superiority over the United States. Too much time had been lost, too much money was needed for that, and the government could not allocate it.

I do not want the readers to think that I am trying to relieve myself as chief designer of responsibility for certain errors committed (including by me personally) during the work on the lunar program.

Only he who does nothing makes no mistakes. We, the successors of S. P. Korolev, did everything we could, but our efforts proved to be inadequate.

Footnotes

1. G. M. Salakhutdinov, "'Apollony' letyat na Lunu" [The Apollos Fly to the Moon], Moscow, Znanie (Seriya: Kosmonavtika, astronomiya, 1988, No 10).

2. The launch vehicles developed for the Apollo/Saturn program are examined in the above-cited booklet by G. M. Salakhutdinov.

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